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High Voltage 6H-SiC Rectifiers: Prospects and Progress

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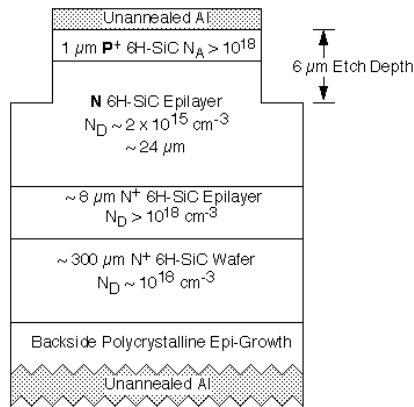
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Silicon carbide (SiC) based semiconductor electronic devices and circuits are currently being developed for advantageous use in high-temperature, high-power, and/or high-radiation conditions under which conventional semiconductors cannot adequately perform. A recent appraisal conducted by Bhatnagar and Baliga [1] indicates that SiC power MOSFET's and diode rectifiers would operate over higher voltage and temperature ranges, have superior switching characteristics, and yet **have die sizes nearly 20 times smaller than correspondingly rated silicon-based devices** which would offset the higher silicon carbide material cost. These improvements arise from the inherent material property advantages that silicon carbide enjoys over silicon, namely a higher breakdown field (> 5 times that of Si) that permits much smaller drift regions (i.e., much lower drift region resistances), a higher thermal conductivity (> 3 times that of Si) that permits better heat dissipation, and a wide bandgap energy (2.9 eV for 6H-SiC) that enables higher junction operating temperatures.

Because silicon carbide semiconductor technology is relatively young and unoptimized, there are several crucial device fabrication issues that must be solved before truly advantageous SiC power devices can be realized experimentally. Background doping concentrations must be reduced if single devices are to standoff multi-kilovolt potentials, and SiC surface passivation techniques will also have to be optimized. Resistive losses due to high specific contact resistivities (presently on the order of $10^{-4} \Omega\text{-cm}^2$) must also be decreased through the optimization of ohmic contact processes. The defects present in silicon carbide must also be reduced if record-high SiC current densities are going to be parlayed into useful large-area high-current power devices.

Through the fabrication of experimental high-voltage epitaxial pn and Schottky junction 6H-SiC diodes, NASA Lewis has recently made progress on some of these issues. Doping concentrations in 6H-SiC epilayers grown by atmospheric pressure chemical vapor deposition have been reduced, **enabling the fabrication of the first 2000 V silicon carbide diode rectifiers ever reported.** A 24 μm thick $2 \times 10^{15} \text{ cm}^{-3}$ n-type epilayer was the key to the 600 V improvement in reported 6H-SiC blocking voltage in the p^+n mesa-structure diodes. The devices on this wafer were small enough (Areas $\leq 4 \times 10^{-4} \text{ cm}^2$) that a 2000 V functional yield in excess of 50% was obtained. Larger area (1 mm^2) pn junction devices exhibited point failures that prevented high-voltage yields above 20%. An investigation into the failure mechanism of the larger-area pn diodes, which typically failed at reverse voltages between 100 V and 400 V, was conducted. In at least half of all the defective diodes, it was found that the points of failure corresponded to micropipe defects in the 6H-SiC. Until such defects are significantly reduced from their present density (~ 100 's of micropipes/ cm^2), 6H-SiC high-voltage device areas will be limited to a few square mm (i.e. 6H-SiC high-voltage single-device currents will be limited to a few amps).

- [1] M. Bhatnagar and B. J. Baliga, IEEE Trans. Electron Devices, vol. 40, no. 3, pp. 645-655, March 1993.

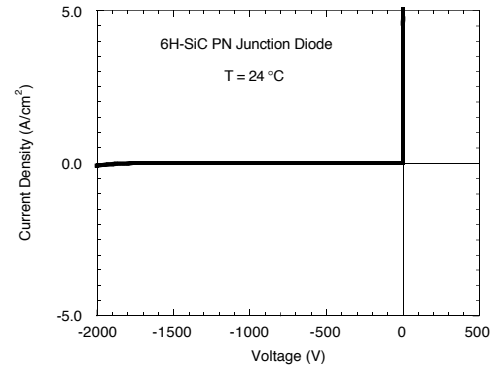
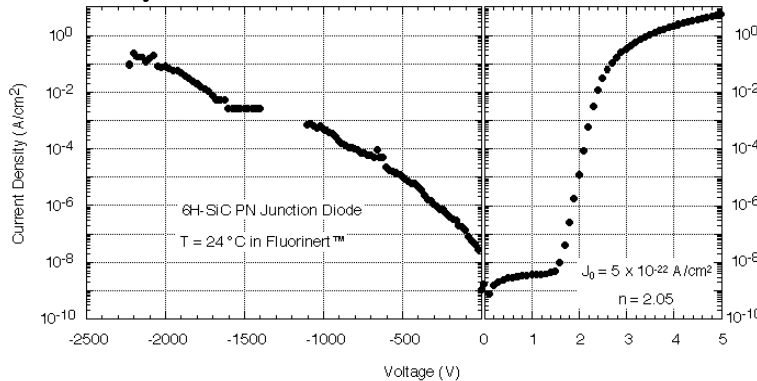


<- Figure 1.

Cross-section of 2000 V 6H-SiC pn junction diodes fabricated in doped epilayers grown by atmospheric pressure chemical vapor deposition. The structure was built solely for the rapid demonstration of record SiC diode reverse blocking voltage capability. The diode's forward turn-on and reverse leakage performance could be improved through the use of optimized ohmic contact metals and cap epilayers, removal of backside polycrystalline material deposited during epilayer growth, and appropriate junction sidewall passivation. Mesas were defined by RIE.

Figure 2.->

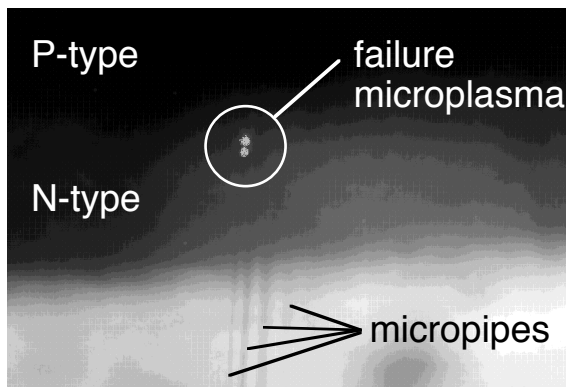
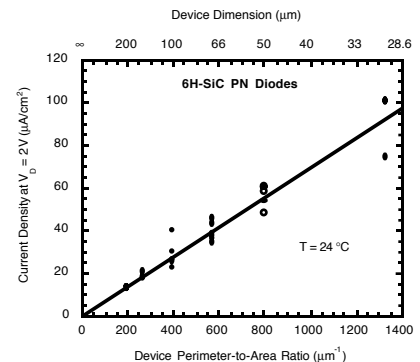
Linear I-V characteristics of a 2000 V 6H-SiC pn junction diode. This curve was taken with the sample immersed in Fluorinert™ (a high dielectric strength insulating fluid) to prevent sparking that occurs across the unpassivated semiconductor surface in air. The devices on this wafer were small enough (Areas $\leq 4 \times 10^{-4} \text{ cm}^2$) that a 2000 V functional yield in excess of 50% was obtained.



<-Figure 3. I-V characteristics of a 2000 V 6H-SiC pn junction diode on a semi-logarithmic scale. The device failed catastrophically at -2200 V before avalanche breakdown could be observed, presumably due to failure of the Fluorinert™.

Figure 4.->

Plot of 6H-SiC pn diode current density at 2 V forward bias ($J(2V)$) versus device perimeter-to-area (P/A) ratio. The zero y-intercept indicates the dominance of surface recombination current arising from the unpassivated etched mesa periphery.



<-Figure 5.

Photo documenting junction failure at a micropipe defect in a 6H-SiC pn diode under 300 V reverse bias. Diodes on the same wafer without such defects in them demonstrated blocking voltages in excess of 1100 V reverse bias. Until such defects are significantly reduced from their present density (~ 100 's of micropipes/cm²), 6H-SiC high-voltage device areas (currents) will be limited to a few square mm (a few amps).